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Cost effectiveness study of weather protection for shipbuidling operations. Volume I.

L. Chirillo˜

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VOLUME I

TODD SHIPYARDS CORPORATION

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Cost Effectiveness Study of Weather Protection of Shipbuilding Operations. VOL I

April, 1974

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Final

This report contains data on how weather factors impact adversely on the shipbuilding process. It is comprehensive, not intended for the casual reader, and useful for the purpose of quantifying losses due to weather. It can serve management to determine how much money should be invested in weather protection devices.

Weather
Productivity
Management hid
Shipbuilding
Shipyard
Ship Construction
Weather Protection

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PRICES SUBJECT TO CHANGE

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4.25

FOREWORD

This study was performed under the National Shipbuilding Research Program. The Program is a cooperative, cost-shared effort between the Maritime Administration's Office of Advanced Ship Development and the shipbuilding industry. The objective, as conceived by the Ship Production Committee of the Society of Naval Architects and Marine Engineers, evaluates productivity increases through the use of shelters.

The research effort contained herein is one of the nine General Category projects being managed and cost shared by Todd Shipyards Corporation. It was performed *in* response to the task statement titled Weather Protection". The work was assigned, by subcontract, to the Battelle Memorial Institute, Pacific Northwest Laboratories (Battelle-Northwest) after evaluation of several proposals.

Study team members of Battelle-Northwest were: T. L. Anderson, Study Manager for the first twelve months of the study; C. H. Henager, Study Manager for the final five months of the study; and C. H. Bloomster who provided the productivity models and economic analysis.

Mr. L. D. Chirillo, Todd Shipyards Corporation, Seattle Division Was the Program Manager.

Special acknowledgement is due also to the many people in the following organizations tor their constructive criticism of this report in its draft form:

Bath Iron Works Corporation

General Dynamics, Quincy Shipbuilding Division

Newport News Shipbuilding and Dry Dock Co.

Avondale Shipyards, Inc.

Designers and Planners, Inc.

EXECUTIVE SUMMARY

This report contains data on how weather factors impact adversely on the shipbuilding process. It is comprehensive, not interded for the casual reader, and useful for the propose of quantifying losses due to weather. It can serve management to determine how much money should be invested in weather protection devices.

Meaningful relationships between productivity in the shipbuilding industry and specific Weather conditions are included. These are based upon a logical separation of crafts, shipbuilders' estimates, use of a hypothetical "standard" shipyard and actual weather data recorded for the fourteen coastal regions in which U.S. shipbuilding yards are located. The relative effects on productivity for each region's weather are contained in Tables 7-1 and 7-2.

The productivity model employed, to predict the weather impact on the "standard" shipyard, is described in Apperdix A, Volume II. Further, it is accompanied by ample instructions and other prerequisites which will enable individual shipyard managers to apply the model to their respective shipyards.

As applied in this report, the results show that substantial savings could be realized by the use of certain weather protection devices. The best combination was the judicious use of hoarding panels (a construction industry innovation--plastic sheets on wood frames) at the shipways to cover only areas where the most work is concentrated, and heated steel buildings with movable roofs to protect platen areas. For a "standard" shipyard, with a volume of $80,000,000 (3-tankers) per year, located near Philadelphia (mid-range weather for U.S. shipbuilding.sites) the following is predicted:

- With an initial investment of $924,000 for 43,200 square feet of heated steel buildings at the platen area and 120,000 square feet of hoarding panels at the shipways, the resultant annual savings fran increased productivity is in the range of $1,000,000 to $1,700,000

Other analyses, based or "standard" shipyard located in each of the fourteen Weather regions considered, yielded the following predictions:

- The cost effectiveness ofvartous types of fecilities was dependent upon the shipyard location. The effectiveness of weather protection facilities is so dependent upon the climatic conditions and the details of the shipyard layout **and** organization that Independent analysis is required to determine the cost effectiveness of a specific facility.
- Covering the outdoor assembly work was cost effective in all locations except southern California.
- Hoarding panels were extremely cost effective at nearly all locations. There is little current application of this method of protection in U.S. shipbuilding.
- At some locations, unheated steel steels, open one side, were more cost effective than the heated steel buildings.
- Portable steel or air-inflatable buildings covering assembly areas were also cost effective, but generally less than the more permanent types of structures.
- A blast, paint and dry facility was marginal for most locations unless painting of panels and subassemblies is on the critical path. In this case, the painting facility would be generally economic at most locations.
- Sun nets were beneficial for the platen areas of most southern shipyards.
- Partial or complete coverage of the shipways with permanent structures was uneconmic or marginal at all shipyard locations.

State-of-the-art surveys of weather protection in the U.S., Japanese and European shipbuilding and heavy construction industries are summarized in Section 2 herein. The state-of-the-art reports of the Japanese and European shipbuilding and heavy construction industries are reproduced in Volume II of this report.

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SECTION 1. INTRODUCTION AND SUMMARY

The purpose of this study was to determine the potential economic advantages of providing weather protection facilities for ship component fabrication and assembly. It was performed in response to a need to reduse shipuilding costs in the United States. It was largely recognized that weatner has a major impact on the shipbuilding process, as it does on the Construction industry. *However,* an evaluation, in terms of the amount of savings possible from weather protection facilities, was needed.

While some limited studies of potential benefits of weather protection facilities have been performed, a study of this magnitude, i.e., encorsassing the U.S. and foreign shipbuilding and neavy construction industries had not previously been attempted. The work involved a great deal of data gathering on weather effects on productivity, types of weather protection available or in use, and weather data itself. Defining adverse weather conditions and estimating productivity increases under protected conditions poses a problem which was solved largely by information supplied by the cooperating U.S. shipyards. The excellent cooperation of the U.S. shipyards in the study contributed materially to the success of this study. Good correlation was obtained between estimates of increased productivity under covered conditions by U.S. shipyards, foreign shipyards, the heavy construction industry and the limited publisned data that was available.

Thus, *the* data and conclusions in this report are founded largely on information obtained from and pertaining to U.S. shipyards. It is believed, therefore, that this report am the productivity models are directly applicable to the L.S. Shipbuilding Industry.

A Productivity model based on the data obtained as described above Was used to analyze eight different weather protection facilities at a hypothetical “standard” shipyard. The model was applied to the shipyard?

using weather data obtained from the Natiaonal Climatic Center for fourteen U.S. shipbuilding locations. These locations were:

Baltimore, Maryland

Boston, Massachusetts

Galveston, Texas

Houston, Texas

Los Angeles, California

Mobile, Alabama

New Orleans, Louisiana

New York, New York

Norfolk, Virginia

Philadelphia, Pennsylvania

Portland, Maine

Portland, Oregon

San Diego, California

Seattle, Washington

The analyses of productivity increases from the use of weather protection facilities at U.S. shipyards showed that substantial savings could be realized by the use of certain facilities. Specifically, the anlyses showed that:

- Covering the outdoor work in the platen assembly areas would be cost-effective in all locations except southern California. Cost-effective covering included portable buildings ("Wonder Buildings"), open-sided sheds, or completely enclosed, heated, facilities. The latter two appear to be so cost-effective that we recommend shipyards outside of southern California analyze the cost-effectiveness of these facilities, independently, for their specific application. Since our analysis was limited to productivity increases directly attributable to weather, greater savings than those indicated would result because covering would also permit the installation of more automated equipment and increase quality.

- Hoarding panels, a heavy construction industry innovation consisting of wood frames and plastic sheet, for work on the shipways and outfitting wharf were extremely cost-effective in nearly all locations. The use of these panels, see Appendix E in Volume II, should be evaluated in greater depth since these are inexpensive and tend to produce a large return on investment. There is little current application of this method of protection in shipbuilding. An easily assembled and disassembled design would be useful for these applications.

- The best combination of weather protection facilities was the use of hoarding panels on the shipways and heated steel buildings with telescoping or removable roofs for the platen areas. In some locations, unheated steel sheds, open *one* side, were most cost-effective in the platen areas than the completely enclosed, heated buildings.

- Portable steel or air-inflatable buildings covering assembly areas were also cost-effective, but generally less than the more permanent type of structures.

- Sun nets were beneficial for the platen areas of most southern shipyards and may also be beneficial for the shipways and outfitting wharf.
- Partial or complete coverage of shipways was uneconomic or marginal at all locations.
- A blasting, painting and drying shop was marginal for the standard shipyard at most locations unless painting of panels and sub-assemblies is on the critical path. In this case, paint shops would be generally economic at most locations.
- Nearly all forms of weather protection devices were found to be uneconomic or marginal for southern California shipyards.

Other conclusions reached in the course of the study were:

- Most shipyard estimates of productivity increases that could be gained from putting outside work under cover were in the range of 20% to 30%.
- There was general agreement among shipyards, the construction industry and the literature that adverse weather conditions significantly reduce productivity in the shipbuilding and heavy construction processes. The weather conditions having the greatest detrimental effect are rain, wind, and cold weather. However all types of adverse weather influence productivity to some extent. These include high temperature, high humidity, fog, snow and sleet.
- Considerable use is presently being made of weather protection facilities in U.S. shipyards in the northern climates. However, much of U.S. shipbuilding is conducted in the open where adverse weather can affect the work.

Recommendations

- Adverse weather has a significant effect on productivity, as indicated by our model. It is recommended that the shipyards conduct specific engineering studies on the effect of weather on the productivity of specific tasks at designated locations to verify the magnitude of these effects.

The present study was based on estimates of the productivity of various crafts under different weather conditions and work locations. Actual measurements of productivity of workers performing various tasks under different climatic conditions would provide a more definitive analysis. Since this is an industry-wide problem which affects our competitive position with foreign shipyards, a cooperative government-industry program much like the present one would appear to be mutually beneficial.

- Investigations of alternative weather protective structure designs and limited test applications need to be made to establish which are the most cost-effective facilities. The demonstrations should be undertaken at selected shipyard locations in order to determine productivity gains under actual adverse weather and to assess the potential cost-effectiveness at other shipbuilding regions.

SECTION 2. STATE-OF-THE-ART OF WEATHER PROTECTION

Introduction

The purpose of this phase of the study was to determine the state-of-the-art in using weather protection devices and facilities for shipbuilding and heavy construction, a closely related industry. Information was sought through the following sources:

- Literature survey
- Questionnaire survey of major U.S. shipyards
- Personal visits to nine U.S. shipyards
- Trade associations (letter contacts)
- Heavy industries (letter contacts)
- Research laboratories (Ietter contacts)
- Survey of European shipyards (subcontract by Battelle-Frankfurt)
- Súrvey of Japanese shipyards (subcontract by Mitsubishi Research Institute)

From each of these sources information was sought on:

- Weather protection facility designs
- Weather effects on productivity
- Weather protection facility costs
- Methods and procedures used to provide weather protection.

Details of the review activities are given in the Appendix, Together they provide the following picture of current use of weather protection in shipbuilding and related industries.

U.S. Shipbuilding Industry

Weathear protection is employed for traditional shipbuilding activities for which it is vitally necessary to have such protection. These are in the form of permanent fixed structures that cover pipe shops, sheet metal work, machine shops, electrical work, warehousing, lofting and offices. In addition, depending upon geographical location, and local practice, the following areas are protected from weather:

- Panel shops
- Ground assembly platen areas
- Pre-outfitting areas
- Blasting and painting areas
- Storage areas
- Shipways and dry docks

Covered panel shops generally house much automated equipment and include crane services, lighting, heating, and ventilation which further add to increased productivity.

In the U.S. the full spectrum of weather protection is seen from Southern California where nearly all operations are *out* of doors to the North Atlantic Coast where the trend is to place nearly all operations under cover.

Portable structures, either fully enclosed or roof shelter only, are frequently used in rainy climates and, in some cases, to provide shade to protect welding, painting, and Llasting operations. Where required by contract, portable rcofs are used to protect high strength steels from rain-caused quenching cracks.

Wood, steel and aluminum are generally used in the construction of portable or mobile buildings. All of the portable structures observed in use in U.S. shipyards are moved by crane. In most instances, the shelters are designed and constructed by the shipyard itself. The only exception observed was the use of “Wonder Buildings”. These are steel frame structures, either arch type or flat roof, covered with large-corrugation sheet metal skins. Portable shelters have ceiling heights varying from about 8 ft to over 30 ft. However, it was reported in the literature that a temporary wooden shack with a 60 ft ceiling height for machinery assembly was in *use.* It was uniformly held that portable buildings not fully enclosed are most effective as sun shades but offer unsatisfactory protection from heavy rain or wind.

Air-inflated buildings for machinery storage have received limited use by some shipyards. Furthermore some yards make considerable use of canvas and tarpaulin to cover subassemblies on platens for local protection and on rare occasions temporary shelters are used to fit deck machinery.

Construction programs involving barges and submarines permit construction to be carried out under fixed or semi-permanent enclosed structures with open ends. Several shipyards noted problems caused by funneled winds in open-ended structures. The more permanent structures have interior overhead cranes and in some instances, provisions were made to move the ship structures o.. railroad dollies.

In *some* situations it was noted that temporary buildings had removable roof panels or hatches to permit overhead access to the covered assembly area. It was generally agreed by shipyard personnel that this form of access was the major disadvantage to providing non-permanent shelter to assembly areas.

Portable shelters without roof access were reported to be efficient only if they could be in place for a week or so. For shorter time periods they are seldom used.

Rain gear is worn by outdoor workers performing maintenance, exterior outfitting, rigging, dry dock operation and for ships' crew. The use of this personal weather protection was observed *to* be universal in the U.S. It was noteworthy that in the northern inclement climatic regions, nearly all outdoor craftsmen carry rain gear at all times in their tool boxes on the job and most outdoor shipbuilding operations continue during light rain or snowfell. Workers in northern climates are used to working out of doors in foul weather gear; they generally find the conditions no different than those they encounter in their recreational activities. The attitude in more southern climates is much different; here inclement weather generally stops outside work.

At shipyards on the Gulf Coast, most of the operations are done in the open and, except for one new yard, this includes sandblasting and painting. Inclement weather, particularly rain, generally stops most outside work if it persists for more than an hour. Portable shelters, and plastic, plywod, and canvas shilds against wind and rain are used for some operations which cannot be delayed. Large beach umbrellas are commonly used to Provide shade from the sun for welding operations.

Some typical weather protection concepts in use in U.S. shipyards are shown in Appendix D. with a few exceptions, they do not represent unique or unusual ideas but reflect a natural outgrowth of the need to bring as. much weather affected work under cover as possible at the lowest cost. Those shipyards on the North Atlantic Coast and North Pacific Coast have much more of their work areas under fixed or portable covers. For the last half-century the tendency in these shipyards has been to bring more of their operations under cover, but marugement does not attribute this trend as an effort to increase worker efficiency. Rather, a cover serves only as an additional incentive *to* provide automation.

It is the universal practice at all shipyards to schedule work to avoid "fighting" the weather insofar as possible. Rescheduling of tasks and reassignment of crafts people *to* covered areas is not fully effective and becomes less so with prolonged periods of inclement weather as accumulated inside jobs are depleted. In some yards a great deal of reassignment of workers is done; in others little *or* no reassignment takes place.

U.S. Heavy Industry

Almost without exception the early completion of capital construction dictates that work must continue 12 months per year. Therefore, *the* records of projects built in severe winter weather areas describe how the work was scheduled to avoid conflicts with the weather insofar as possible. Where it is *not* possible to schedule weather-sensitive activities to avoid inclenent weather, temporary weather protective measures are employed.

A general practice in the construction of temporary shelters is to use wood or steel or pipe frames covered with tarpaulin, polyethylene, plywood or sheet metal. There is widespread use of small portable shelters to protect welding work from rainfall in order to maintain weld-quality. References 1 to 7 describe specific applications, problems and benefits of the *use* of temporary shelters.

A typical type of temporary or portable weather protection system is described in Appendix E. Modular panels are used to provide winter protection for construction work areas. From the illustrations shown it is easy to visualize the *use* of these panels in a variety of portable shelter systems . Appendix E also illustrates a lightweight temporary work shelter which has been successfully used in the construction industry.

It seems to be the general opinion that local craftsmen's ability or willingness to work in adverse weather is almost completely a regional characteristic. For example, workmen in the Pacific Northwest are accustomed 'o working in the rain. Workmen in the Gulf Coast area are accustomed to working in hot humid weather. Contractors working in each of these areas believe they experierice relatively good industrial production productivity. It is also the general belief that absenteeism varies geographically for different weather conditions. An example was cited where southern states' workers vanish with the second rain drop even in the summer. The same thing happened in the summer rain in Canada, but these same craftsmen would workk outside in miserable snow, sleet, and wind conditions through the winter.

Some cases have been cited where inflatable shelters have been *used,* but these are normally provided only for storage of material because access is limited to the practical size of the openings required for air locks.

However, Appendix F describes the experience of one contractor with the use of an air-supported structure whose physical dimensions were lOO ft wide, 200 ft long and 50 ft high. This facility was used to provide shelter to a construction site.

Reference 10 serves as an excellent guide to design and erection of air-supported structures; several case studies are given. Other examples of the use of air-supported structures are given in References 8 and 9.

European Shipbuilding Industry

Shipbuilding in Europe is shifting to an increasing extent from non-protected, open air space to weather-protected areas. Weather-protected facilities insure improvements in working productivity and working conditions. The small and medium sized shipyards in adverse climatic regions are AMELS, IHC-SMIT and LINZ shipyards and have erected and put into operation halls for shipbuilding activities. In some cases entire building docks and Slipkway areas have been covered.

Most of the large shipyards in northwest Europe have not or only partially been able to realize the concept of total inside shipbuilding up to now because the capital costs for such large covered facilities do not appear to justify the increased output. The shipyards in many cases do not have a large enough order backlog to justify such investments.

The following is a summary of weather protection facilities of various types and the associatd shipbuilding activities carried out therein.

- Halls with fixed roof

  Construction: Steel or reinforced concrete with overhead bridge cranes

  Shipbuilding Activity: Marking, burning, welding, panel an section erection

- halls with traversing roofs

  Construction: Steel or reinforced concrete with overhead bridge cranes or other cranes working from the outside through the open roof

  Shipbuilding Activity: Barking, burning, welding, panel and section erection

- Movable halls

  Construction: Steel frame and steel or other material, sheeting moved by vehicle and laborers

  Shipbuilding Activity: Marking, burning, welding, assembling and erecting panel sections

- Sheds

  Construction: Steel

  Shipbuilding Activity: Sand blasting, painting, storage and general purpose use

- Shacks

  Construction: Wood

  Shipbuilding Activity: Storage and general purpose

- Portable Roofs

  Construction: Steel frame with corrugated metal sheeting; moved by crane

  Shipbuilding Activity: Marking, burning, welding and painting

- Tarpaulin Shelters and Tents

  Shipbuilding Activity: Burning, welding, painting, storage and general purpose

The final report describing Battelle-Frankfurt's activities in surveying current practice in the use of weather protection facilities in the European shipbuilding industry is contained in the Appendix. Specific examples of shipyard modernization involving weather protection facilities are described in the following paragraphs.

A roofed building slip at IHC-Smit Shipyard in the Netherlands was completed in October 1972. The hall consisting of three sections accommodates the entire steel shipbuilding up to launching. The hall can accom. modate ships of 460 foot lengths and 75 foot beam. The hall dimensions are 551 feet by 167 feet by 111 feet high, Ventilation is provided through ventilation channels and fixed exhausts located within the roof. Heating is provided by infrared devices.

Decision to construct the roofed building hall was based upon a major reorganization of the shipyard. The desire to accomplish shipbuilding in all weather conditions was definitely included in the decision to go ahead with the construction. It'S noteworthy to point *out* that the shipyard considered need for craft laborers to have protection and more readily accessible working spaces.

The Makkum shipyard located in the Netherlands started a large modernization program in 1968. The first part of the program was completed in November 1971. The first structure completed was a roofed building dock with dimensions of 393 feet by 62 feet by 23 feet and a larger hall of dimensions 415 feet by 121 feet by 93 feet. All shipbuilding operations can be carried out within these structures. At both ends of the building hall there are sliding doors with a clear width of nearly 61 feet. These doors are driven electrically and can be remotely controlled. Above the sliding doors which extend up to the crane track there are wing doors which permit the overhead bridge cranes to roll *out* of the hall and make lifts from the outside. The hall is illuminated by mercury vapor lamps and natural lighting is provided through plastic windows. The hall is ventilated and heated. Future plans call for extending the building dock 262 feet and the hall 426 feet.

The small LINZ shipyard in Austria put into services new shipbuilding hall in March of 1962. Its dimensions are 328 feet by 114 feet by 79 feet. There were several reasons for building the hall and altering the conventional procedure of shipbuilding: 1) the need to carry out shipbuilding activities without the influence of adverse weather conditions, 2) increased productivity, 3) eliminate uncertainties in work planning, and 4) improve work quality.

Similar modernization programs have been carried *out* at Appledore Shipbuilders, Limited, on the north coast of Devon, England, and at

Trondhjems Mek. Verksted, Norway. These are both" small yards accommodating construction of up to 10,000 tons and 3,000 tons, respectively. In each case their small size permits a nearly totally enclosed shipyard, including complete covering of the drydock.

Europe's largest building dock (1968) is at Kockums Mek Verkstads. Their facility consists of a block assembly hall arranged in line with the vast building dock. The dock and building hall together are well over one-third of a mile long and are spanned by an 800 ton capacity Goliath gantry crane. This crane runs on rails extending from the dock gate to the landward end of the hall. The hall has no end door but the roof sections can slide apart to provide areas through which large sections can be lifted. The shipbuilding hall is 590 feet long by 243 feet wide and 130 feet high and is of reinforced concrete construction. At one corner a large door permits access for delivery of subsections prefabricated at another facility.

The roof consists of six, 350 ton sections each 98 feet long. These are self-powered and large sections of the roof can be lifted out. The hall itself is served by two gantry cranes of 80 ton capacity each.

Japanese Shipbuilding Industry

Under subcontract, Mitsubishi Research Institute, Inc. conducted a study for determining the state-of-the-art of the *use* of weather protection in the Japanese shipbuilding industry. Their report is included in the Appendix. The following is a brief summary of their findings.

Japanese experience in weather protection for outdoor shipbuilding work is unique and has a history of nearly two decades in many shipyards. Weather protection facilities in these yards is one of the major factors leading *to* increased productivity in the Japanese shipbuilding industries allowing them, to increase their competitive edge in the world market with foreign shipbuilders.

As with U.S. and European shipyards, the types of weather protection devices used depend strongly on the differences in the duration of operation of a shipyard since their establishment and subsequent modernization programs.

The differences in weather protection devices among the Japanese shipyards are as follows. In the old, conventional-type,shipyards the outdoor construction and hull construction yard were changed and arranged to fit the fabrication of large welding, block assembly areas. This was undertaken during the latter half of the 1950's. For example in the case of the Nagasaki yard, a huge roof was constructed over welding and small block assembly areas. The result was a covered assembly factory with movable roof sections for the construction of hull units ranging from 50 to 80 metric tons each. These are lifted directly onto adjacent building berths by gantry cranes. Subsequently, crane capacities have been increased to provide lifts to 120 tons. At the Nagasaki yard, only about 14% of the hull construction work is carried on outdoors.

This move to place previous outdoor welding and assembly areas under cover has been carried out in general by similar construction at the other major shipyards on the Pacific coast of Japan during the period 1955 to 1965.

Planning and construction of new shipyards in Japan around 1960 resulted in the construction of yards patterned somewhat after Swedish examples of advanced shipbuilding technology and some of their novel ideas were incorporated into the layout of shops within the yards. At their inception, for the most part, historically outdoor construction was planned to be done under cover using large movable roofs for protection. For example, in the Yokahama shipyard there are five indoor welding and block assembly shops each 853 feet long and 150 feet wide. Each of these has movable roofs. Subassemblies over 100 tons can be fabricated in these shops and lifted through the open roof by gantry crane.

In a third group of new shipyards even the large building docks are partially covered by movable roofs. In the Koyagi shipyard the maximum size of hull block which can be assembled within the shops is 600 tons. Over the building dock which is 3,182 feet long and 328 feet wide, there are two sets of traveling roofs each 164 feet long and 328 feet wide. At this yard the final stage of ship construction is partially weather protected. This newest shipyard began operation in 1973.

It is clear that there has been a trend in Japanese shipbuilding to provide weather protection for traditional outdoor work. This was done by the use of either fully enclosed buildings with fixed roofs, or with permanent buildings utilizing traveling roofs or roofs that move to allow access for overhead cranes. The latter seems to be the predominant construction. A survey in 1970 revealed the following for the percent of block assembly areas that are covered:

1. Twenty-seven to eighty-seven percent for shipyards built prior to 1960;
2. Fifty-one to ninety percent for those built from 1961 to 1970; and
3. One-hundred percent for those built after 1970.

A more recent survey in 1972 showed that the area coverd of block assembly shops for Item 2 above has increased to the range seventy tc one-hundred percent.

Photographs illustrating typical roofed assembly areas and details of traveling roof sections are given in the MRI report in the Appendix.

Japanese experience with complete roofing of block assembly shops indicates an increase in productivity in the range of 20 to 30% can be realized. They attribute this increase to:

1. An ability to continue work despite rain,
2. Shortened time required for arranging assembly blocks due to improved facilities and
3. Improvement in working environment due to a nearly uniformly maintained temperature.

In the way of personal protection provided to workers, weather windbreakers and trousers are supplied to all outdoor welders-for protection from the cold in northern Japan. In the central and western parts of Japan, outfits for protection from cold are provided to several thousand outdoor workers. Each workshop has heating devices installed as required to allow workers to warm themselves. However, no measures for protection from cold are taken in workshops which are not completely covered.

There are five itms used for personnel protection from weather:

1. Ventilating fans
2. Coolers/heaters
3. Water coolers
4. Clothing
5. Sun nets

Ventilating fans are used in the block assembly shops, the pre-erection shops, on the building berth and dock and in the painting and coating shops. The category of coolers and heaters includes steam heaters, warm air.blowers, gas stoves, electric heaters, coal stoves, oil heaters, etc. In some shipyards,- spot cooler units are used to blow cool air through ducts into a shop or into compartments of ships on the dock. Japanese experience has shown that spot cooler units decrease temperatures in tanks and other areas on the average of 37°F, reduce moisture 3-5% and substantially lower the discomfort index. Water coolers are commercially available types and used where appropriate.

Specialized weather protection clothing consists of the following: portable body warmers (hand warmer type), winter waistcoat, mufflers, ear muffs and other winter clothing. For work in hot weather wide use is made of so-called cool suits. These are vest-like garments into which compressed air is fed through a bag contained in the vest to provide cooling. Some shipyards supply dry ice to the outdoor workers to combat heat. The practice has been to pack dry ice into a felt bag and place this in their helmet. The ice is changed twice a day and has proven to be quite effective. It has been reported, however, that this use was suspended recently in many shipyards.

The fifth category of weather protection devices. are sun nets used to provide shade to workers in outdoor working shops and, on deck. These are light “camouflage net” covers supported by ropes and/or a light frame. Use of sun nets is universal in the Japanese shipbuilding industry. Cool suits are provided at about half of the shipyards.

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13. "Europe's Largest Building Dock," Marine Engineer and Naval Architect, January 1968.

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SECTION 3. DESCRIPTION OF THE STANDARD SHIPYARD

General

The productivity models were applied to a hypothetical "Standard" shipyard to obtain estimates of the cost effectiveness of various categories of weather protective structures. The purpose of the standard shipyard was to provide a yardstick against which anticipatd benefits of this and other R&D programs could remeasured. The standard shipyard description was developed by J. J. McMullen Associates as a part of a study on "Ship Productivity - Determination of Task Priorities," dated May 1973. It describes both a "standard" shipyard and a "standard" ship.

The standard ship is a "Panamax" type of tanker with an overall length of 820 feet, a breadth of 105 feet, a depth of 60 feet and a displacement of 91,250 tons. Other particulars of the ship and its construction which are pertinent to this study are shown in the Appendix (Volume II).

It should be pointed out that the "standard" shipyard is entirely synthetic, having been created from a number of basic production requirements constrained by a number of typical environmental factors; although it is intended to be a standard United States "shipyard, rather than a foreign one, any resemblance to any other shipyard, whether existing or defunct, is purely coincidental. It should be kept in mind that it is a tool for comparative analyses and is not intended to be an "optimum" shipyard.

The Standard Shipyard

In formulating the standard shipyard, it was assumed that the standard shipyard, although built before World War II, has modernized its facilities to the fullest extent possible given its geographical and structural limitations.

It was also assumed that the shipyard has an annual steel throughput of approximately 40,000 tons, equivalent to three standard ships a year.

It was further assumed that the standard shipyard is engaged in merchant ship construction only and all naval and repair work is contained within a separate and distinct organization.

Although virtually all U.S. shipyards are involved simultaneously in both merchant and naval shipbuilding and shiprepairing, the impacts of cost reduction tasks on commercial ship costs can only be effectively evaluated if those costs are isolated from the shipyard's other activities. The implication of this assumption for the definition of the standard shipyard is that the labor force is perfectly balanced and fully occupied, a condition that can only be true in a shipyard building a single product, a standard ship, since variations in product mix inevitably result in variations in labor function requirements.

The support workforce required by a standard shipyard with a direct labor workforce of 2038 was defined as 458 additional employees (for a total of 2496).

This proportion represents the position of the standard shipyard as an approximately average yard in the spectrum of U.S. shipbuilding.

Facilities and Production Processes in the Standard Shipyard

Steel arrives by rail and is unloaded and sorted by a gantry magnet crane in a stockyard of about 60,000 square feet, employing a horizontal storage and having a capacity for one shipset of steel. The standard plate size is 45 feet by 10 feet, although the maximum could be 48 by 12. This standard size is directly related to the design of the standard ship, 45 feet being one half of the tank length, and hence to the panel construction method.

The steel is fed by conveyor, via a surface preparation line involving the usual cleaning, mangling, blasting, painting and drying processes, into a fabrication shop of about 40,000 square feet, divided into four bays, quipped for sections, flat panel material, shaped panel material and the reminder. The fabrication shop is equipped with the conventional cold forming machinery, template-controlled, and automatic burning machinery, optically-controlled. There is no numerical control. An overhead crane of 15 tons spans each bay.

The section and flat panel material bays lead into a flat panel assembly shop of about 20,000 square feet, featuring eight working areas, of 2,500 square feet each, for the construction of flat panels of plating with associated longitudinal and transverse framing, up to a maximum size of 48 feet by 30 feet, and averaging 60 tons each. Welding is semi-autoratic, both of plate butts and of stiffening, and material is moved and Dcsitioned using three overhead cranes, two of 75 tons and one of 15 tons. Average panel construction time is four to five days. The other two fabrication bays lead into a shaped panel assembly shop, also of about 20,000 square feet, where working areas are laid out as required for the more complex shaped panels. Welding is semi-automatic or manual and material is moved and positioned by means of similar cranage to the flat panel shop. Average panel construction time is eight to ten days.

All completed steel assemblies are moved outside to a paint shop where welds are cleaned and painted and then to storage areas or directly to the shipways: multi-wheel heavy-load transporters are used for these movement.

Machinery and outfit materials are received both by road and by rail and held in conventional warehousing and other storage areas until required. Machinery and outfit “work packages” are put together in various shops, mostly of an earlier generation, and delivered to work stations by truck or forklift. These packages are normally but not necessarily trade-oriented: they may include material for several different operations planned to take place in the same work place. Limited panel outfitting takes place in the steel assembly snops, being confined to the fitting of attachments for piping, cable trays and ventilation ducting.

Ship erection is carried out on one of two shipways, starting with stern panels and working forward and upward. Each shipway is big enough for the standard ship with a working margin of 5 feet on each side and 30 feet on the length, but no more. Each is served by four whirley cranes:

- two of 50 tons max. lift at 75 feet max. outreach
- one of 35 tons max. lift at 75 feet max. outreach
- one of 25 tons max. lift at 75 feet max. outreach.

as shown in the sketch presented as Figure 1. Average erection time is eight months, at an average work rate of approximately one panel per day.

After launching, each ship is moved to a single outfit wharf where its stay averages four months.

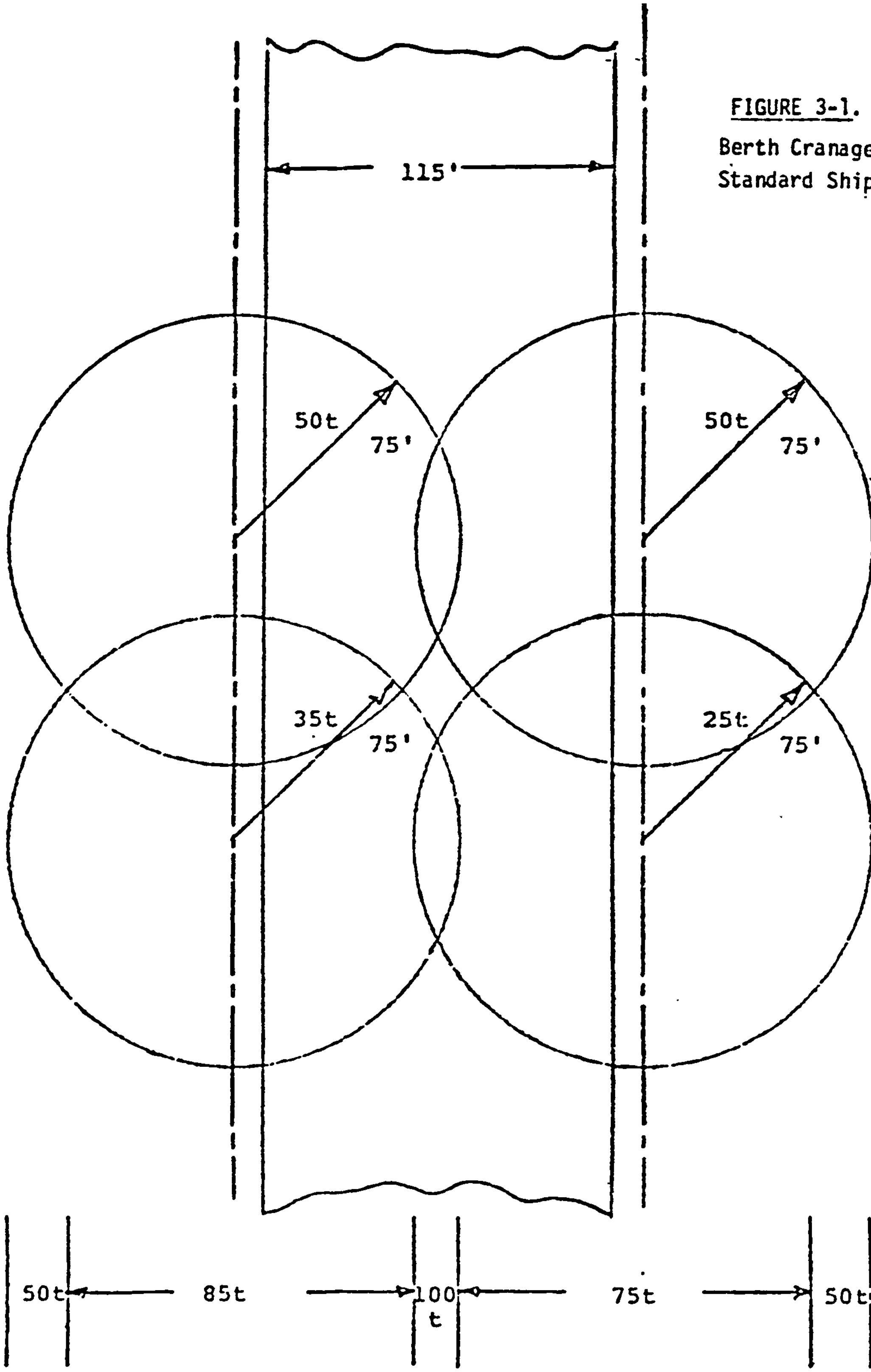

FIGURE 3-1.
Berth Cranage in the Standard Shipyard

MINIMUM LIFT CAPACITIES

Outdoor Operations in the Standard Shipyard

The indoor operations and facilities and the outdoor shipways are described in the preceding pages.

The approximate uses and areas for outdoor operations which could be covered for weather protection were assumed to be in the ranges shown below:

Description	Area
Steel stockyard operation	60,000 sq.ft.
Machinery and outfit storage areas for bulky items of a non-weather-sensitive nature	As required
Cleaning and painting of welds on steel assemblies	100,000sq.ft. minimum
Panel storage (or module assembly, if desired) with associated pre-outfitting (if not completed in the assembly shop) or further pre-outfitting following module assembly including fitting of as many of the following items as seems appropriate to the shipyard management:	20,000 Sq.ft. minimum, up to 80,000 sq.ft.

pipes
valves and other pipefittings
ventilation ducts
cable trays
cable runs
doors
manholes
skylights
hull openings
ladders
heating coils
interior painting
exterior painting
machinery room outfit
accommodation fitting to the extent that it is possible.

SECTION 4. CATEGORIES OF WEATHER PROTECTION AND THEIR COSTS

The productivity models were applied to the "standard" shipyard using several categories of weather protection.

Various building types and amounts of area covered were analyzed to find their cost effectiveness. In doing this a basic assumption used was that, where possible, all operations should be put under cover. Exception~ to this were areas where benefits in productivity would obviously be low or non-existent such as covering the steel storage yard or a camplete covering of the outfitting wharf where nearly all the work is already under cover by the ship.

Building categories were selected as being typical of structures currently in use or of a type practically available for *use* in shipyards.

They included the following types:

- A contiguous, blasting, painting and drying facility, which would provide humidity and temperature control for these operations.
- Rolling buildings or buildings with movable roofs for module assembly and pre-outfitting work, heated but not cooled.
- Large steel sheds open one side for module assemblies and pre-outfitting work, not heated or cooled.
- Movable temporary shelters, steel and air-inflatable, for protection of small subassemblies, not heated or cooled.
- Hoarding panels (plastic covered panels on wood frames) selectively placed at the shipways and outfitting wharf, not heated or cooled.
- Movable roofs at the shipways, not heated *or cooled.*
- Sunshades for platen areas.
- A complete covering of the shipways, climate controlled, providing total protection in all weather.

The maximun subassembly, or module, size was assumed from the standard shipyard data to be 48 feet by 30 feet by about 25 feet high averaging 60 tons. This required building heights of about 40 feet to accommodate sections. Since not all modules would be the maximum size, some building heights of 30 feet and 20 feet were also provided. Data on the buildings, their *costs,* extent of protection provided and other data are summarized in Table 4-1.

The heading “Productivity Penalties or Gains without Weather” in Table 4-1 accounts for the loss of productivity in certain buildings due to requirements for crane access. The actual cost of moving a roof to gain access, or positioning a portable shelter for weather protection was not factored into the model. It was assumed that the increase in costs for such positioning would be negligible because they would be largely offset by potential savings also not included in the model. These savings included reduced maintenance on equiment, reduced water removal costs, and savings on weather-related material losses.

The cost of the hoarding panels, shown in Table 4-1 as $0.50/sq.ft. of panel installed, is conservatively estimated from data received from construction firms and a manufacturer of closure panels for weather protection of buildings under construction. It includes the cost of erection and dismantling. Generally, this cost would apply to small *enclosures* or to locations where scaffolding, parts of the ship structure, open building walls or similar structures are available for support of the panels. For large structures or locations where additional support structure is required, the cost would be increased by the cost of the additional support. For estimating purposes, a cost of $1/sq.ft. is suggested for such installations. At this cost the hoarding panel scheme is cost-effktive at most locations (see Section 7 “Application of the Productivity Model to the Standard Shipyard”).

Table 4-1

WEATHER PROTECTION FACILITIES FOR STANDARD SHIPYARD

Type of Building	Sq. Ft.	Type of Work Protected	Crafts and No. Protected	Extent of Weather Protection	Productivity Penalties or Gains w/o Weather
1. Blast, paint and dry facility -3 bays @ 50'x150' - total 150' x150'x40' high, climate controlled. Steel frame constr.	22,500	Blasting, painting and drying of parts, subassemblies and modules.	Blasters and painters (15)	100% protection from rain wind, high and low temp., humidity.	None (crane access not req'd, assemblies in and out on wheeled transporter.)
2. Steel bldg. for cover of platen, subassembly pre-out fit, and module areas. Telescoping sections, entire bldg. or roof only, for overhead crane access. Size 60'x120' or larger by 40' high. (heated but not cooled)	Up to 43,200 total (can be divided between several structures)	Burning, welding, fitting electrical sheet metal, in pre-outfitting subassemblies and modules	Burners and welders (80) Fitters (100) Riggers* (0) other crafts (6)	100% protection from rain, wind, low temp, and fog. Provides shade but no cooling.	For crane access at 1 hr/shift with roof rolled back, productivity is same as uncovered. 7/8 time at 100%. 1/8 time at uncovered rate.
3. Large steel sheds open one side - same use and size as 2, above, (not heated, not cooled)	Up to 43,200 total (can be divided between several structures)	Same as 2, above	Same as 2, above	100% protection from rain and 50% protection from wind. Provides shade but no heating, cooling or humidity protection.	None Crane access by jib cranes thru open side of bldg. (crane cost included in building cost).
4. Complete covering of shipways-each bldg. 230'x850'x130' high of steel constr. covering cranes. End doors for moving subassy's modules in by transporter and for launching - climate controlled	195,500 each bldg, 391,00 ft^2 total	All work in shipway	Craft (outside**) (in ship**) Burners and welders (121) (208) Blaster and painters (23) (13) Fitters (120) (186) Riggers (24) (35) other crafts (29) (105) (pipefitters, electr. machinists, sht mtl)	100% protection in all weather	No Penalties Saves all of water removal costs on ships at shipways; reduced maintenance on equipment from rain damage, etc.

*Riggers assumed to be outside nearly all the time.
**Figure in first parenthesis is workers originally outside, not protected from weather; figure in second parenthesis is workers originally outside but protected by ship structure.

Table 4-1
WEATHER PROTECTION FACILITIES FOR STANDARD SHIPYARD (Continued)

Type of Building	Capital Cost $/ft^2	Capital Cost Total	Est. Life Years	Annual Costs for Total Area Listed - $ Heating(1)	Lighting(2)	Ins. & Taxes(3)	Rep. & Maint.(4)	Cooling
1. Blast, paint and dry facility. 22,500 ft^2 total	$25	$562,500	20	0.9*	338	16,875	28,125	See Table 4-2
2. Steel bldgs. for cover of platen - etc. 43,200 ft^2 total (6 Bldgs)	$20	$864,000	25	1.728*	648	25,920	25,920	0
3. Large steel sheds open one side. 43,200 ft^2 total (6 Bldgs)	$15	$648,000	25	0	432	19,440	6480	0
4. Complete covering of shipways. 391,000 ft^2 total (2 Bldgs) 50,830,000 ft^3	-	$13,600,000	25	50.83*	5865	408,000	680,000	See Table 4-2

(1) Heating at $0.000001/degree-day/cu. ft./year* Note: Multiply listed figure by - Heating degree days per year for various locations.
(2) Lighting at $.015/ft^2/year for 1, 2, 4, & 8; $.01 for 3 and 5; others not lighted.
(3) Ins. and Taxes at 1.5% of capital cost, each/year.
(4) Repairs & Maint. at 5% for 1 & 4; 3% for 2, 5 and 8; 1% for 3, 6 and 7.
Includes maint of Bldg. and equipment (heating, cooling, vent and painting equip.) but not cranes, welding equip., machine tools, etc.

Table 4-1

WEATHER PROTECTION FACILITIES FOR STANDARD SHIPYARD (Continued)

Type of Building	Sq. Ft.	Type of Work Protected	Crafts and No. Protected	Extent of Weather Protection	Productivity Penaltie or Gains w/o Weather
5. Temporary Shelters (movable), shade and rain protection only, open both ends (no heating or cooling) a. steel, b. air inflatable	up to 43,000 ft^2 (several shelters up to 60'x 60')	Same as 2, above	Same as 2, above	100% protection from rain. Provides shade but no cooling or wind protection.	Same as 2, above
6. Sunshades for platen areas (apply to ship-way and outfitting wharf based on cost/ft^2 and numbers craft protected/ft^2) Nylon netting	up to 43,000 ft^2 (several sunshades up to 40' x 40')	Same as 2, above	Same as 2, above	Provides shade but no cooling. No wind or rain protection.	Same as 2, above
7. Hoarding panels, (plastic sheets on wood frames or scaffolding. Wind and rain protection - selectively placed on shipways and outfitting wharf, removable roof	Up to 120,000 ft^2 (several modules)	50% of all work at shipping and outfitting wharf	Craft (shipway) (outfit) Burn and weld (60) (13) Blast and Paint (10)(11) Fitters (60)(8) Riggers* (0)(0) other crafts (15) (11) (P.F., elec. mach. sht. mtl)	100% protection from rain and wind. No protection for cold temp., high temp. or humidity	Same as 2, above Saves up to 1/2 of water removal costs on ship
8. Movable roofs at shipway - 2 each shipway, each 160' long x 120' wide x 130' high	76,800 ft^2 4 roofs (covers 40% of ships at shipway)	50% of all work at shipway.	Burn & weld (60) Blast and paint (10) Fitters (60) Riggers* (0) other Crafts (15) (FF, elec., mach., sht mtl)	100% protection from rain, 75% protection from wind. Provides shade but no cooling. No protection from cold temp. or humidity	Same as 2, above; saves up to 1/2 of water removal costs on ship in shipways.

*Riggers assumed to be outside nearly all the time.

Table 4-1

WEATHER PROTECTION FACILITIES FOR STANDARD SHIPYARD (Continued)

Type of Building	Capital Cost $/ft^2$	Capital Cost Total	Est. Life Years	Annual Costs for Total Area Listed - $ Heating(1)	Lighting(2)	Ins. & Taxes(3)	Rep. & Maint.(4)	Cooling
5. Temporary Shelters (movable)								
a. Steel(5)	3.75	$162,000	10	0	432	4860	4860	0
b. Air inflatable 43,200 ft^2 total	3	$129,000	3	0	432	3888	3888	0
6. Sunshades for platen areas 43,200 ft^2 total	2	$86,400	5	0	0	2592	864	0
7. Hoarding panels 120,000 ft^2 roof and wall surface	0.50	$60,000	6 mos.	0	0	1800	600	0
8. Movable roofs at shipway 76,800 ft^2	35	$2,688,000	25	0	1152	80,640	80,640	0

(1), (2), (3), (4) See notes on previous page.
(5) Fifty percent of steel shelters are 20 ft high; 25% are 30 ft high, 25% are 40 ft high; cost shown is a composite.

TABLE 4-2. Annual Heating and Cooling Costs for Facilities 1, 2, and 4

Location	Normal Heating Degree Days	Annual Heating Cost $/Year Facility 1	Annual Heating Cost $/Year Facility 2	Annual Heating Cost $/Year Facility 4	Cooling Degree Days	Annual Cooling Cost $/Year Facility 1	Annual Cooling Cost $/Year Facility 4
Portland, ME	7511	6,800	13,000	38,000	<500	600	11,000
New York, NY	5219	4,700	9,000	27,000	1250	1,600	29,000
Baltimore, MD	4654	4,200	8,000	24,000	1500	1,900	34,000
Portland, OR	4635	4,200	8,000	24,000	<500	600	11,000
Norfolk, VA	3421	3,100	5,900	17,000	2000	2,500	47,000
Houston, TX	1676	1,500	2,900	85,000	3500	4,400	81,000
Galveston, TX	1235	1,100	2,100	63,000	3500	4,400	81,000
Seattle, WA	5145	4,600	8,900	26,000	<500	600	11,000
Philadelphia, PA	5101	4,600	8,800	26,000	1400	1,800	33,000
San Diego, CA	1439	1,300	2,500	73,000	<500	600	11,000
Mobile, AL	1693	1,500	2,900	86,000	3000	3,800	68,000
Boston, MA	5634	5,100	9,700	29,000	1000	1,300	23,000
Los Angeles, CA	1799	1,600	3,100	91,000	<500	600	11,000
New Orleans, LA	1385	1,200	2,400	70,000	3250	4,100	74,000

Capital costs of various weather protective structures, such as those used in the productivity model, were obtained from several sources. These included replies to the questionnaires sent to individual shipyards (actual building costs were supplied), *cost* estimating handbooks, and specific estimates of proposed buildings by shipyards. Good agreement was found among these sources and with a tabulation of costs prepared by the SNAME panel SP-1 (Facilities) in a report “Weather Protection in Shipyards,” April 1971. That tabulation, as revised and amended for this study, is shown in Table 4-3. These costs are suitable for a preliminary evaluation. However, when the productivity model is applied to a specific structure, preliminary engineering and bids from a subcontractor are the best basis for final cost evaluation.

Table 4-3

TABULATION OF UNIT COSTS - VARIOUS TYPE BUILDINGS

BUILDING TYPE	PERMANENT	PORTABLE	UNIT COST DOLLARS/SQ.FT.	REMARKS
1. Heavy Multi-Story Warehousing, Fire Proof Construction, including all services.	X		25 to 35	Conventional
2. Light Multi-Story Warehousing, Fire Proof Construction, including all services.	X		15 to 25	Conventional
3. Single Story Crane Warehousing, Fire Proof Construction, including all services but excluding cranes.	X		15 to 25	Conventional
4. Light Warehousing, Single Story, Fire Proof Construction - Pre-fab.	X		10 to 20	Butler or equal
5. Heavy Manufacturing Building, Single Story, Fire Proof Construction, including all services but excluding cranes.	X		25 to 30	Suitable for enclosing large platen or assembly areas, drydocks, etc.
6. Assembly Platen Cover with provision for telescoping sections, either entire cover or roof only, if crane. access is from above. Steel.	X	X	10 to 15	Shelter for platen areas, assembly areas.
7. Large Steel Sheds-open one side.	X		5 to 8	Shelter for large sub-assemblies for pre-outfitting or similar activities.

Table 4-3 Continued

TABULATION OF UNIT COSTS - VARIOUS TYPE BUILDINGS

BUILDING TYPE	PERMANENT	PORTABLE	UNIT COST DOLLARS/SQ.FT.	REMARKS
8. Temporary Steel Shelters		X	3 to 5	Quonset Hut Type
9. Small Sheet Metal Buildings		X	5 to 10	Various services
10. Air Inflated Buildings	See Remarks		3 to 5	particularly suited for short term warehousing or special purpose uses.
11. Wood Shacks		X	3 to 5	General Purpose.
12. Covering of Existing Overhead Shipway or Drydock Crane Structure to provide weather protection.	X		30 to 50	Possible only if existing structure can resist, or be made to resist, appropriate wind, snow and dead loads.
13. Hoarding Panels. Plastic sheets over wooden frames and scaffolding (Temporary)		X	0.35 to 0.50 per square foot of panel	General purpose selectively placed
14. Arched Roof Shelters no side walls, steel		X	2 to 3	General Purpose
15. Tents, Canvas or Coated Fabric		X	2 to 5	Short term Warehousing or Special Purpose.

SECTION 5. EFFECTS OF WEATHER ON SHIPBUILDING

5.1 Effects of Weather on Productivity

A main objective of this program was to develop the relationship between productivity in the shipbuilding industry and specific weather conditions. A review of the literature (Appendix C) provided little information relating productivity to weather, that could be directly applied to shipbuilding. However, two shipyards provided internal company reports on the effects of weather which helped to formulate the scope of our study, and, later, to provide independent cross-reference points. Since company records were not available directly relating productivity to weather, this relationship was developed primarily from interviews with shipyard personnel, supplemented with data obtained from the literature and questionnaires.

Among those interviewed, there was unanimity that cold, heat, wind, rain, snow, humidity, sunshine, and fog all affected worker productivity. The critical points at which a specific weather condition had a decided effect on productivity was also in general agreement. For instance, everyone agreed that temperatures below freezing or above 90°F adversely affected productivity. Also, there was consistent agreement that winds above 25 mph, almost any precipitation, direct sunshine on hot days, and heavy fog all affected productivity. There was also consistent agreement on ideal weather conditions; temperatures between 50-70°F, light wind or calm, and no precipitation. All agreed to these ideal conditions, but many thought the limits should be a little broader. These broader limits were used to define ideal weather in developing a model, described later, relating productivity to weather. As expected, humidity combined with heat and wind combined with cold were consistently mentioned as adverse conditions.

There was again consistent agreement between the shipyards and the personnel interviewed that each craft and work location was affected somewhat differently by weather conditions. For instance, humidity, per se, primarily affected the painters and heavy fog primarily affected the riggers and crane operators. There was agreement also that the weather would have decidedly different effects on productivity depending on the location of the worker; obviously an outdoor worker was more affected than one within a ship and one within a ship was more affected than one within a shop.

Curiously, paint foremen in two shipyards reported slowdowns, apparently psychological, during inclement weather of painters assigned to indoor work.

In addition to labor productivity we obtained information on the effect of weather conditions on absenteeism, employee turnover, accidents, material losses, reject or rework rates, scheduling slippages, excess equipment capacity, and other factors which would lead to increased costs. Some of these factors were beyond the control of shipyard management, such as some absenteeism caused by bad road conditions, sickness, or hunting seasons; in many cases cost savings would not be achieved with the addition of weather protection facilities. A listing of increased cost items attributable to weather by the shipyards is shown in Table 5-1. Because the relationship between costs and weather was not consistent between shipyards, some of these cost items were omitted from our analysis. Our results, therefore, probably understate the total costs attributable to weather (see Appendix A).

Pay for idle time, pass-out conditions, and transfer time between work locations varied between shipyard locations. The most common practice covering pass-out conditions was two hours pay for reporting to work, a minimum of four hours pay if workers are put to work, and pay for time worked over four hours. Only one yard reported use of the radio and television in advising workers not to report to work. All yards attempted to transfer workers to protected areas to the maximum extent possible. Estimates of lost time in transferring between work locations varied from 1/2 to 1-1/2 hours, with one hour being the most typical value. All yards also apparently attempted to pass workers out to the minimum extent possible. Except for rare occasions, pass outs were entirely for precipitation.

5.2 Weather Data

Historical records of weather observations are kept by the National Climatic Center, Department of Commerce, Asheville, N.C. However, retrieval for specific purposes requires preparation of a special computer program to accumulate the observations into the categories selected.

TABLE 5-1. Increased Shipbuilding Costs Attributed to Weather

Increased Labor Costs

1. Idle time in shifting work locations.
2. Lower productivity caused by cold-wind (chill factor).
3. Lower productivity caused by heat-humidity (comfort index).
4. Rework caused principally by rain or moisture for blasters and painters; rework caused principally by cold for welders (usually high-strength steel cracking).
5. Extra manpower to tend equipment in cold weather.
6. Extra work for water and snow removal, bleeding air lines, etc.
7. Premium pay to complete work rescheduled because of weather.
8. Passout pay.
9. Absenteeism and turnover.
10. Rework of bad welds caused by wind.
11. Rework caused by Differential Thermal Expansion.

Increased Material Costs

1. Paint loss in wind.
2. Extra fuel consumption
   a. vehicles
   b. outside heating
   c. space heating.
3. Parts lost under snow or mud cover.

Increased Equipment and Facilities Costs

1. Weather protective structures
   a. permanent
   b. temporary
2. Heaters and heating equipment
3. Blowers and fans
4. Snow and water removal equipment
5. Stuck or idle vehicles
6. Excess or idle capacity

Safety

1. Occasional shutdowns because of slippery or unsafe working conditions.
2. Shutdowns because of heat and fatigue.
3. More burns to welders in warm weather - less protective clothing.

General

1. Shutdowns caused by bad roads.
2. Fixed overhead and working capital costs allocated to reduced production.

A decennial census of the United States' climate was published for the period 1951-1960. This census contained a summary of hourly observations at weather stations near each of the coastal shipbuilding locations. Since the period of ten years was sufficient to eliminate short-term weather fluctuations and since many of the observations were detailed by time of day, we selected this census data on which to base our analysis. Annual summaries of hourly observation are included in Appendix B, exhibit A. The main deficiency in this summary for our purposes was that the temperature-wind observations were not reported by time of day. However, since the relative humidity was reported by time of day (see Table C of the annual summary) and since the simultaneous temperature-wind-relative humidity occurrences were reported (see Table A of the annual summary), we were able to disaggregate Table A into the three work shifts (Appendix B, exhibit B). Disaggregation of Table A by this means produced observation totals for each shift which were accurate to within 1 . Hourly precipitation data were not available for Seattle and Mobile from the census reports. For these locations, a special retrieval of precipitation data, covering a five-year period, was provided by the National Climatic Center.

5.3 Definition of Ideal and Adverse Climatic Conditions

For the purposes of the productivity model described later ideal weather is defined as temperature between 40 and 79°F, wind less than 12 mph, and a trace or no precipitation. Adverse climatic conditions are defined simply as all conditions which are not ideal. Stop work conditions occur for winds greater than 25-40 mph, precipitation greater than 0.1 in./hr, extreme heat or cold, relative humidity greater than 90% or temperature below 35°F for painters. Productivity is assumed to be 100% under ideal weather conditions, zero under stop work conditions, and between zero and 100% under other adverse conditions. It is assumed that the relative severity of the adverse climatic conditions is approximately proportional to the relative productivity loss caused by the condition. In our usage, 100% productivity represents a reference level and does not imply maximum productivity.

SECTION 6. DEVELOPMENT OF A PRODUCTIVITY MODEL

6.1 Description

Using the information gathered from the interviews and other sources, a productivity model was developed to simulate productivity in the "standard" shipyard under different weather conditions. A computer program was written to perform the rather extensive calculations involved. Productivity under ideal weather conditions was used as the reference level and assigned a value of 1.0 (100%). Adverse weather conditions were assigned values less than 1.0. Estimates of productivity between the ideal and stop-work conditions *were* based upon the estimates of superintendents and craft . foremen, the information available in the literature, interpolation between ideal and stop-work conditions, and our interpretation of the subjective observations of the shipyard personnel. Productivity in the shops was assumed to be 1.0; i.e., equal to outside productivity under ideal weather conditions. Extreme weather conditions, such as hurricanes, record freezes, heavy snowfall, and prolonged periods of precipitation,were excluded from the model because of their rarity and uniqueness to specific locations. These conditions and their associated costs were so variable between locations that their inclusion would have been detrimental to the general application of the mdel.

Five craft categories (painters, welders, riggers, fitters, and all other crafts combined) and three work locations (outside-not protected, protected by the ship structure, and in a shop) were selected to represent the standard shipyard. The number of workers by craft and location in the standard shipyard was estimated. Also, the distribution of workers by shift was estimated. Three shift operation was assumed; 65% day, 30% after-noon, and 5% night. This distribution was assumed to apply to each craft category and each work location.

Based on the information obtained from the questionnaires, interviews, and the literature, estimates were made of the relative productivity under each type of weather condition, for each craft, and location. Details of the productivity model and sample calculations are given in Appendix A.

The model makes no allowance for acclimatization; i.e., workers in all shipyard locations were assumed to respond similarly to cold, heat, and other weather conditions. Some degree of acclimatization is certain, but its effect on productivity is uncertain. For example, a northern shipyard was the only one which reported closure for extreme heat, while some Gulf Coast shipyards were the only ones reporting closures for below freezing weather. Closures during cold weather in northern shipyards were always attributed to bad road conditions, not cold.

The productivity model combined the frequency of each adverse weather category on each shift with the estimated productivity to determine the relative productivity of each craft by weather category, shift, and location. These productivities, in turn, were accumulated to obtain the relative productivity by craft, by location, and for the shipyard in total. For example, Table 6-1 shows the relative annual productivity of an outside welder in Baltimore on day shift for each temperature category. The productivities in this table are obtained by multiplying the frequency of occurrence of each temperature category by the productivity for each category. The productivity for each temperature category includes the effect of wind, rain, cloud cover, humidity, and fog occurrences on productivity. Under ideal weather conditions, the total productivity Would be 1.000. Similar tables are calculated for all combinations of craft, shift, work locations, and shipyard locations.

Occurrences of rain, wind, cloud cover, fog and relative humidity were assumed to be independent of temperature; each was assumed to occur with the same relative frequency for each temperature category. Under this assumption the relative productivity attributed to each separate condition was determined from the frequency of occurrence. The relative productivities for each separate condition then could be-multiplied together with the productivity for each temperature category to determine the average annual productivity for that temperature category. A sample calculation is included in Appendix A.

TABLE 6-1. Productivity of Outside Welders on Day Shift in Baltimore[a]

Effective Temperature Range °F	Fraction of Annual Productivity	Frequency of Occurrence
<5	.005	.023
5-19	.048	.110
20-29	.094	.157
30-39	.128	.163
40-79	.355	.415
80-89	.062	.107
90-99	.009	.025
100+	.000	.000
ANNUAL TOTAL	.701	1.000

a. This is an example of one table of 140 possible combinations of craft, shift, work location, and shipyard location. See Appendix A for a summary of productivities for each shipyard location.

Included in the model is an algorithm to cover pay and transfer time for pass-out conditions. This algorithm with an example calculation is described in Appendix A. It was assumed that workers would be passed out only for precipitation. Under typical pay conditions for pass outs, it is advantageous before mid-shift to the shipyard to transfer workers to protected conditions to the maximum extent possible rather than pass them out (Table 6-2). As observed previously, the shipyards tended to avoid pass-out situations. Very few man days relative to the total were reported lost for this reason.

TABLE 6-2. Relative Pay and Productivity of Workers Transferred to Protected Locations and Passed Out During Each Hour of a Shift

Occurrence of Precipitation (Beginning Hour of the Shift)	Worker Transferred to Protected Location			Worker Passed Out		
	Hours of Add.* Pay	Add. Hours of Work	Ratio Hr. Worked to Hr. Pay	Hours of Add. Pay	Add. Hours of Work	Ratio Hr. Worked to Hr. Pay
1	8	7	0.875	2	0	0
2	7	6	0.857	1	0	0
3	6	5	0.833	2	0	0
4	5	4	0.800	1	0	0
5	4	3	0.750	0	0	0
6	3	2	0.667	0	0	0
7	2	1	0.500	0	0	0
8	1	0	0.000	0	0	0

*Add. = Additional.

6.2 Interpretation of the Relative Productivity Value

The productivity model is used to calculate the effect of the weather conditions at each of the selected locations on the relative annual productivity of the standard shipyard placed near each location. The relative annual productivity may be interpreted in several ways: 1) this ratio is the relative amount of work a given work force would accomplish in an average weather year in each yard, 2) the inverse of this ratio is the relative size of work force needed to accomplish the required work in an average year, 3) the inverse of this ratio is a measure of the relative overtime requirements, or 4) this ratio is a measure of the relative length of the construction schedule and, thus, related to the capacity of the shipyard.

Thus, the same relative productivity value can cover a range of potential dollar costs or savings. When we applied the productivity model, we used this range to determine the costs attributable to weather and the potential savings with weather protection facilities. The low value in the range pertains to the second interpretation that additional labor is readily available to fill the needs. The only cost to the shipyard is the extra straight-time wages for additional workers. The high value in the range results when the productivity loss is met through overtime premium pay. Some value in midrange is probably typical of most shipyards.

The calculation of potential cost savings related to productivity gains for the standard shipyard is shown in Appendix K. As a rule of thumb, a 1% productivity gain at the standard shipyard will result in a cost savings of $300,000-$500,000, depending on which of the above assumptions applies.

SECTION 7. APPLICATION OF THE PRODUCTIVITY MODEL TO THE STANDARD SHIPYARD

Applying the productivity model to actual weather data for each location, the relative productivity (Table 7-l) of the standard shipyard placed near each shipbuilding location was calculated. San Diego and Los Angeles had near ideal shipbuilding weather, losing less than 3% productivity to weather, according to our model. The highest losses attributed to weather were nearly 15% in Portland, Maine, and Boston. These losses are lower than some of the estimates we received of up to 30% annual loss.

7.1 Annual Cost Savinqs Througs Transfers

Since all shipyards attempted to work around the weather by transferring worker; outside in good weather and inside in bad weather, we calculated the potential increase in productivity and annual cost savings attainable in each location through transfers (Table 7-2). Equivalent productivity gains may result in slightly different cost savings at different locations because the relative percentage gain from the base productivity (Table 7-l) is different. This analysis assumed that all workers in the shipyard would be assigned to outside work during ideal weather. Any surplus man-hours of outside work were transferred back to protected locations in non-ideal weather; first to the locations protected by the ship's structure, then any further surplus was transferred to the shop. Although less than 1% increase in total shipyard productivity was achieved under these assumptions, the potential dollar savings in some locations was substantial.

7.2 Benefit-Cost Analysis for Various Types of Weather Protection

The model was applied to each shipyard location to determine the gain in productivity and the resulting cost savings for each of the eight types of weather protection described previously. The probable extent of amelioration of adverse weather conditions by each facility was previously estimated. For instance, heated buildings were assumed to maintain ideal working temperature in cold weather, and a four-sided roofed building was

TABLE 7-1. Relative Effect of Weather on Productivity Near U.S. Shipbuilding Locations

Location	Average Annual Productivity	Loss in Productivity Attributed to Weather
Portland, ME	0.852	0.148
Boston	0.854	0.146
Houston	0.875	0.125
Baltimore	0.878	0.122
New York	0.883	0.117
Galveston	0.886	0.114
Philadelphia	0.888	0.112
Norfolk	0.895	0.105
Mobile	0.897	0.103
New Orleans	0.905	0.095
Seattle	0.907	0.093
Portland, OR	0.927	0.073
Los Angeles	0.973	0.027
San Diego	0.982	0.018

TABLE 7-2. Estimated Increases in Productivity Achievable from Transferring Workers to Outside Work During Ideal Weather

Location	Increase in Productivity	Annual Savings $
Seattle	0.008	290,000--460,000
Portland, OR	0.008	270,000--420,000
Boston	0.006	240,000--400,000
New York	0.006	230,000--370,000
Baltimore	0.006	230,000--370,000
Norfolk	0.006	220,000--360,000
Portland, ME	0.005	210,000--330,000
Mobile	0.005	190,000--300,000
Philadelphia	0.005	190,000--300,000
Houston	0.005	160,000--310,000
Galveston	0.004	150,000--250,000
Los Angeles	0.003	90,000--150,000
New Orleans	0.001	40,000-- 60,000
San Diego	0.001	30,000-- 50,000

assumed to offer complete protection from the wind, rain, and sun. In addition, the number of workers of each craft protected by each facility was estimated. From this information, the potential increase in productivity for each facility was calculated and converted into annual cost savings. The cost savings were compared with the annualized cost of the facility to determine the benefit-cost ratio. The annualized cost (Table 7-3) included both capital and operating expenses.

TABLE 7-3. Annual Costs of the Weather Protection Facilities

Facility	Annual Capital Cost @ 15% Rate of Return	Annual Operating Cost ($)	Total ($)
1. Paint Shop	89,865	45,338	135,203
2. Steel Assembly Bldg.	133,661	52,488	186,149
3. Steel Assembly Shed	100,246	26,352	126,598
4. Shipways Bldg.	2,103,920	1,093,865	3,197,785
5. Steel Portables 20'	11,835	3,996	15,831
30'	7,532	2,700	10,232
40'	10,760	3,672	14,432
Total	30,127	9,504	39,631
Air Inflatables 20'	23,651	3,672	27,323
30'	13,008	2,214	15,222
40'	14,191	2,376	16,567
Total	50,850	7,398	58,248
6. Sun Nets	25,775	3,456	29,231
7. Hoarding Panels	138,000	4,800	142,800
8. Shipway Roofs	415,834	162,432	578,266

The annualized capital expense was computed to provide a 15% return on investment before income taxes over the useful life of the facility. Operating expenses included heat, light, cooling, maintenance, insurance, and property taxes. Estimated heating and cooling costs, which vary with location, were shown earlier in Table 4-2. These costs are added to the annual costs shown in Table 7-3. A benefit-cost ratio above 1.0 implies a rate of return on investment above 15%. A benefit-cost ratio below 1.0 implies a rate of return less than 15%.

The results of our analysis for each of the eight types of weather protection facilities are discussed individually below. Benefit-cost ratios were calculated for both the high value and the low value in the potential cost savings range described previously. We will regard facilities with benefit-cost ratios less than unity for the high range as unfavorable, facilities with the ratio less than unity in the low range and more than unity in the high range as marginal, and facilities with both ratios above unity as favorable.

Facility 1: Climate-Controlled Paint Shop

The paint shop (Table 7-4) has favorable benefit-cost ratios in Boston and Portland, Maine, and potential deficits in San Diego, Los Angeles, New Orleans, and Portland, Oregon. For the other locations, the paint shop is marginal.

In Table 7-4 and subsequent tables for each facility, column 2, "Total Shipyard Productivity Increase", refers to the average annual increase for all workers. The small increase in overall productivity is somewhat misleading, since it is spread over the entire work force and masks the large increases in productivity of the individuals protected. Columns 3 and 4, "Annual Savings", show the range of savings resulting from the productivity increase. As mentioned previously, equivalent productivity increases result in different savings in different locations because the percentage increase from the base productivity is different. Column 5, "Annual Cost", shows the annualized cost for each facility. For heated and cooled facilities, this cost varies with the heating and cooling degree days at each location. Columns 6 and 7, "Net Annual Savings (Loss)", show the range of annual savings minus the annual costs. Annual losses are shown in parentheses. Columns 8 and 9, "Savings to Cost Ratio", show the ratio of columns 3 and 4 to column 5.

TABLE 7-4. Estimated Cost Effectiveness of facility 1 for US Shipyard Locations

Location	Total Shipyard Productivity Increase (Fractions)	Annual Savings $ Low	Annual Savings $ High	Annual Cost($)	Net Annual Savings (Loss)$ Low	Net Annual Savings (Loss)$ High	Savings To Cost Ratio Low	Savings To Cost Ratio High
Baltimore	0.003	116,000	188,000	141,000	(25,000)	47,000	0.8	1.3
New Orleans	0.002	74,000	117,000	140,000	(66,000)	(23,000)	0.5	0.8
Portland, OR	0.002	70,000	112,000	140,000	(70,000)	(28,000)	0.5	0.8
Norfolk, VA	0.003	112,000	181,000	141,000	(29,000)	40,000	0.8	1.3
Portland, ME	0.004	165,000	265,000	143,000	22,000	122,000	1.2	1.9
New York	0.003	114,000	184,000	141,000	(27,000)	43,000	0.8	1.3
Houston	0.003	117,00	189,000	141,000	(24,000)	48,000	0.8	1.3
Galveston	0.003	115,000	184,000	141,000	(26,000)	43,000	0.8	1.3
Seattle	0.003	110,000	176,000	140,000	(30,000)	36,000	0.8	1.3
San Diego	0.001	31,000	51,000	137,000	(106,000)	(86,000)	0.2	0.4
Mobile	0.003	111,000	179,000	140,000	(29,000)	39,000	0.8	1.3
Boston	0.004	164,000	264,000	142,000	22,000	122,000	1.2	1.9
Los Angeles	0.001	32,000	51,000	137,000	(105,000)	(86,000)	0.2	0.4
Philadelphia	0.003	114,000	183,000	141,000	(27,000)	42,000	0.8	1.3

TABLE 7-5. Estimated Cost Effectiveness of Facility 2 for US Shipyard Locations

Location	Total Shipyard Productivity Increase (Fractions)	Annual Savings $ Low	Annual Savings $ High	Annual Cost($)	Net Annual Savings (Loss)$ Low	Net Annual Savings (Loss)$ High	Savings To Cost Ratio Low	Savings To Cost Ratio High
Baltimore	0.018	686,000	1,106,000	194,000	492,000	912,000	3.5	5.7
New Orleans	0.009	327,000	525,000	189,000	138,000	336,000	1.7	2.8
Portland, OR	0.012	414,000	660,000	194,000	220,000	466,000	2.1	3.4
Norfolk, VA	0.015	553,000	890,000	192,000	361.000	698,000	2.9	4.6
Portland, ME	0.022	1,887,000	1,427,000	199,000	688,000	1,228,000	4.4	7.2
New York	0.019	716,000	1,152,000	195,000	521.000	957,000	3.7	5.9
Houston	0.013	502,000	807,000	189,000	313,000	618,000	2.7	4.3
Galveston	0.012	453,000	729,000	188,000	265,000	541,000	2.4	3.9
Seattle	0.017	608,000	980,000	195,000	413,000	785,000	3.1	5.0
San Diego	0.002	62,000	100,000	189,000	127,000	(89,000)	0.3	0.5
Mobile	0.015	550,000	885,000	189,000	361,000	696,000	2.9	4.7
Boston	0.025	999,000	1,609,000	196,000	803,000	1,413,000	5.1	8.2
Los Angeles	0.004	126,000	204,000	189,000	63,000	15,000	0.6	1.1
Philadelphia	0.016	599,000	963,000	195,000	404,000	768,000	3.1	4.9

TABLE 7-6. Estimated Cost Effectiveness of Facility 3 for US Shipyard Locations

Location	Total Shipyard Productivity Increase (Fractions)	Annual Savings $ Low	Annual Savings $ High	Annual Cost($)	Net Annual Savings (Loss)$ Low	Net Annual Savings (Loss)$ High	Savings To Cost Ratio Low	Savings To Cost Ratio High
Baltimore	0.012	460,000	742,000	127,000	233,000	615,000	3.6	5.8
New Orleans	0.006	219,000	351,000	127,000	91,000	224,000	1.7	2.8
Portland, OR	0.008	277,000	446,000	127,000	150,000	319,000	2.2	3.5
Norfolk, VA	0.009	334,000	538,000	127,000	207,000	411,000	2.6	4.2
Portland, ME	0.010	409,000	658,000	127,000	282,000	531,000	3.2	5.2
New York	0.011	418,000	674,000	127,000	291,000	547,000	3.3	5.3
Houston	0.009	349,000	561,000	127,000	222,000	434,000	2.7	4.4
Galveston	0.009	341,000	548,000	127,000	214,000	421,000	2.7	4.3
Seattle	0.007	360,000	581,000	127,000	233,000	454,000	2.8	4.6
San Diego	0.002	62,000	100,000	127,000	(65,000)	(27,000)	0.5	0.8
Mobile	0.008	295,000	476,000	127,000	168,000	349,000	2.3	3.7
Boston	0.013	527,000	848,000	127,000	400,000	721,000	4.1	6.7
Los Angeles	0.003	75,000	153,000	127,000	(32,000)	26,000	0.7	1.2
Philadelphia	0.009	340,000	546,000	127,000	213,000	419,000	2.7	4.3

TABLE 7-7. Estimated Cost Effectiveness of Facility 4 for US Shipyard Locations

Location	Total Shipyard Productivity Increase (Fraction)	Annual Savings $ Low	Annual Savings $ High	Annual Cost($)	Net Annual Savings (Loss)$ Low	Net Annual Savings (Loss)$ High	Savings To Cost Ratio Low	Savings To Cost Ratio High
Baltimore	0.065	2,356,000	3,793,000	3,469,000	(1,113,000)	324,000	0.7	1.1
New Orleans	0.053	1,835,000	2,953,000	3,342,000	(1,507,000)	(389,000)	0.5	0.9
Portland, OR	0.039	1,308,000	2,104,000	3,445,000	(2,137,000)	(1,341,000)	0.4	0.6
Norfolk, VA	0.055	1,941,000	3,125,000	3,419,000	(1,478,000)	(294,000)	0.6	0.9
Portland, ME	0.077	2,920,000	4,700,000	3,591,000	(671,000)	1,109,000	0.8	1.3
New York	0.060	1,163,000	3,481,000	3,492,000	(2,329,000)	(10,000)	0.3	0.99
Houston	0.066	2,401,000	3,864,000	3,364,000	(963,000)	500,000	0.7	1.1
Galveston	0.059	2,115,000	3,404,000	3,342,000	(1,227,000)	62,000	0.6	1.0
Seattle	0.047	1,630,000	2,625,000	3,471,000	(1,841,000)	(846,000)	0.5	0.8
San Diego	0.010	380,000	545,000	3,282,000	(2,944,000)	(2,737,000)	0.1	0.2
Mobile	0.054	1,999,000	1,608,000	3,352,000	(2,353,000)	(1,744,000)	0.3	0.5
Boston	0.075	2,839,000	4,567,000	3,507,000	(668,000)	1,060,000	0.8	1.3
Los Angeles	0.014	438,000	705,000	3,300,000	(2,862,000)	(2,595,000)	0.1	0.2
Philadelphia	0.057	2,039,000	3,281,000	3,490,000	(1,451,000)	(209,000)	0.6	0.9

It was estimated that 1/2 of the platen assembly area could be adequately protected with 20'- high structures, 1/4 with 30', and 1/4 with 40' structures; the overall cost-effectiveness of this distribution for steel portables is shown in Table 7-8. Because of their longer life, the steel facilities are more cost-effective than the same distribution of air inflatable structures (Table 7-9). Considering each height separately, lower relative costs make the 20' buildings more cost-effective than the 30', which are better than the 40' (Tables 7-10 and 7-11). For each of the heights, it was assumed that the same number of workers would be protected per unit building area.

Facility 6: Sun Nets for Platen Assembly Areas

Facility 6 (Table 7-12) is cost-effective in the hotter climates, particularly Galveston, Mobile, Houston, and Norfolk. It is marginal in New Orleans, Baltimore, New York, and Philadelphia. It is not cost-effective in the other cooler or cloudier areas. As with Facility 5, only a slight gain in overall productivity is achieved. However, the low cost of the sun net is sufficient in many areas to be cost-effective. The Japanese use sun nets quite extensively in their southern shipbuilding yards (see Appendix H).

Facility 7: Hoarding Panels for Shipways and Outfitting Wharfs

Facility 7 (Table 7-13) is cost-effective in all locations, perhaps even including San Diego. Again, slight increases in productivity are sufficient to offset the small cost of the hoarding panels. The hoarding panels were assumed to provide no additional weather protection and no productivity gain to workers within the ship. Each installation of hoarding panels was assumed to last six months. The savings in many locations are high enough to permit economic installation for periods as short as two to three months.

Facility 8: Movable Buildings Partially Covering Shipways

Facility 8 is marginal at Boston, New York, and Portland, Maine, but it is not cost-effective for the standard shipyard at any other location (Table 7-14). Wind protection is a major factor at Boston which has a

TABLE 7-8. Estimated Cost Effectiveness of Facility 5 Steel Total for US Shipyard Locations

Location	Total Shipyard Productivity Increase (Fraction)	Annual Savings $		Annual Cost($)	Net Annual Savings (Loss)$		Savings To Cost Ratio	
		Low	High		Low	High	Low	High
Baltimore	0.0027	105,000	169,000	40,000	65,000	129,000	2.6	4.2
New Orleans	0.0028	103,000	164,000	40,000	63,000	124,000	2.6	4.1
Portland, OR	0.0031	109,000	174,000	40,000	69,000	134,000	2.7	4.4
Norfolk, VA	0.0029	108,000	175,000	40,000	68,000	135,000	2.7	4.4
Portland, ME	0.0025	103,000	166,000	40,000	63,000	126,000	2.6	4.2
New York	0.0025	96,000	154,000	40,000	56,000	114,000	2.4	3.9
Houston	0.0035	129,000	208,000	40,000	89,000	168,000	3.2	5.2
Galveston	0.0035	134,000	215,000	40,000	94,000	175,000	3.4	5.4
Seattle	0.0023	109,000	176,000	40,000	69,000	136,000	2.7	4.4
San Diego	0.0018	24,000	41,000	40,000	(16,000)	1,000	0.6	1.0
Mobile	0.0036	133,000	215,000	40,000	93,000	175,000	3.3	5.4
Boston	0.0029	119,000	191,000	40,000	79,000	151,000	3.0	4.8
Los Angeles	0.0013	41,000	66,000	40,000	1,000	26,000	1.0	1.7
Philadelphia	0.0029	110,000	177,000	40,000	70,000	137,000	2.8	4.4

TABLE 7-9. Estimated Cost Effectiveness of Facility 5 Air Inflatable Total for US Shipyard Locations

Location	Total Shipyard Productivity Increase (Fraction)	Annual Savings $ Low	Annual Savings $ High	Annual Cost($)	Net Annual Savings (Loss)$ Low	Net Annual Savings (Loss)$ High	Savings To Cost Ratio Low	Savings To Cost Ratio High
Baltimore	0.0027	105,000	169,000	58,000	47,000	111,000	1.8	2.9
New Orleans	0.0028	103,000	164,000	58,000	45,000	106,000	1.8	2.8
Portland, OR	0.0031	109,000	174,000	58,000	51,000	116,000	1.9	3.0
Norfolk, VA	0.0029	108,000	175,000	58,000	50,000	117,000	1.9	3.0
Portland, ME	0.0025	103,000	166,000	58,000	45,000	108,000	1.8	2.9
New York	0.0025	96,00	154,000	58,000	38,000	96,000	1.7	2.7
Houston	0.0033	129,000	208,000	58,000	71,000	150,000	2.2	3.6
Galveston	0.0035	134,000	215,000	58,000	76,000	157,000	2.3	3.7
Seattle	0.0030	109,000	176,000	58,000	51,000	118,000	1.9	3.0
San Diego	0.0008	24,000	41,000	58,000	(34,000)	(17,000)	0.4	0.7
Mobile	0.0036	133,000	215,000	58,000	75,000	157,000	2.3	3.7
Boston	0.0029	119,000	191,000	58,000	61,000	133,000	2.1	3.3
Los Angeles	0.0013	41,000	66,000	58,000	(17,000)	8,000	0.7	1.1
Philadelphia	0.0029	110,00	177,000	58,000	52,000	119,000	1.2	3.1

TABLE 7-10. Cost Effectiveness of 20', 30', and 40' Portable Steel Buildings Covering Platen Assembly Areas

Location	20' Low	20' High	30' Low	30' High	40' Low	40' High
Baltimore	3.3	5.3	2.6	4.2	1.9	3.0
New Orleans	3.2	5.1	2.6	4.1	1.8	2.9
Portland, OR	3.4	5.4	2.7	4.4	1.9	3.1
Norfolk, VA	3.4	5.5	2.7	4.4	1.9	3.1
Portland, ME	3.2	5.2	2.6	4.2	1.8	3.0
New York	3.0	4.8	2.4	3.9	1.7	2.8
Houston	4.0	6.5	3.2	5.2	2.3	3.7
Galveston	4.2	6.7	3.4	5.4	2.4	3.8
Seattle	3.4	5.5	2.7	4.4	1.9	3.1
San Diego	0.8	1.3	0.6	1.0	0.4	0.7
Mobile	4.2	6.7	3.3	5.4	2.4	3.8
Boston	3.7	6.0	3.0	4.8	2.1	3.4
Los Angeles	1.3	2.1	1.0	1.7	0.7	1.2
Philadelphia	3.4	5.5	2.8	4.4	2.0	3.2

TABLE 7-11. Cost Effectiveness of 20', 30', and 40' Air Inflatable Buildings Covering Platen Assembly Areas.

Location	20' Low	20' High	30' Low	30' High	40' Low	40' High
Baltimore	1.9	3.1	1.8	2.8	1.5	2.5
New Orleans	1.9	3.0	1.7	2.7	1.5	2.4
Portland, OR	2.0	3.2	1.8	2.9	1.6	2.6
Norfolk, VA	2.0	3.2	1.8	2.9	1.6	2.6
Portland, ME	1.9	3.1	1.7	2.8	1.5	2.4
New York	1.8	2.9	1.6	2.6	1.4	2.3
Houston	2.4	3.9	2.2	3.5	1.9	3.1
Galveston	2.5	4.0	2.2	3.6	2.0	3.2
Seattle	2.0	3.3	1.8	2.7	1.6	2.6
San Diego	0.4	0.8	0.4	0.7	0.4	0.6
Mobile	2.5	4.0	2.2	3.6	2.0	3.2
Boston	2.2	3.5	2.0	3.2	1.8	2.8
Los Angeles	0.8	1.2	0.7	1.1	0.6	0.97
Philadelphia	2.0	3.3	1.8	3.0	1.6	2.6

TABLE 7-12. Estimated Cost Effectiveness of Facility 6 for US Shipyard Locations

Location	Total Shipyard Productivity Increase (Fraction)	Annual Savings $ Low	Annual Savings $ High	Annual Cost($)	Net Annual Savings (Loss)$ Low	Net Annual Savings (Loss)$ High	Savings To Cost Ratio Low	Savings To Cost Ratio High
Baltimore	0.0007	27,000	44,000	29,000	(2,000)	15,000	0.9	1.5
New Orleans	0.0007	26,000	41,000	29,000	(3,000)	12,000	0.9	1.4
Portland, OR	0.0002	7,000	11,000	29,000	(22,000)	(18,000)	0.2	0.4
Norfolk, VA	0.0008	30,000	49,000	29,000	1,000	20,000	1.03	1.7
Portland, ME	0.0002	8,000	13,000	29,000	(21,000)	16,000	0.3	0.4
New York	0.0005	20,000	31,000	29,000	(9,000)	2,000	0.7	1.1
Houston	0.0017	66,000	106,000	29,000	37,000	77,000	2.3	3.7
Galveston	0.0021	81,000	129,000	29,000	52,000	100,000	2.8	4.4
Seattle	0.0001	4,000	6,000	29,000	(25,000)	(23,000)	0.1	0.2
San Diego	0.0002	8,000	12,000	29,000	(21,000)	(17,000)	0.3	0.4
Mobile	0.0015	56,000	90,000	29,000	(27,000)	61,000	1.9	3.1
Boston	0.0003	12,000	20,000	29,000	(17,000)	(9,000)	0.4	0.7
Los Angeles	0.0002	6,000	10,000	29,000	(23,000)	19,000	0.2	0.3
Philadelphia	0.0005	19,000	31,000	29,000	(10,000)	2,000	0.7	1.1

TABLE 7-13. Estimated Cost Effectiveness of Facility 7 for US Shipyard Locations

Location	Total Shipyard Productivity Increase (Fractions)	Annual Savings $ Low	Annual Savings $ High	Annual Cost($)	Net Annual Savings (Loss)$ Low	Net Annual Savings (Loss)$ High	Savings To Cost Ratio Low	Savings To Cost Ratio High
Baltimore	0.013	499,000	803,000	143,000	356,000	660,000	3.5	5.6
New Orleans	0.007	256,000	409,000	143,000	113,000	266,000	1.8	2.9
Portland, OR	0.010	346,000	556,000	143,000	203,000	413,000	2.4	3.9
Norfolk, VA	0.011	407,000	656,000	143,000	264,000	513,000	2.8	4.6
Portland, ME	0.013	530,000	854,000	143,000	387,000	711,000	3.7	6.0
New York	0.016	605,000	973.000	143,000	462,000	730,000	4.2	6.8
Houston	0.010	387,000	623,000	143,000	244,000	480,000	2.7	4.4
Galveston	0.010	378,000	609,000	143,000	235,000	466,000	2.7	4.3
Seattle	0.014	503,000	810,000	143,000	360,000	667,000	3.5	5.7
San Diego	0.002	62,000	100,000	143,000	(81,000)	(43,000)	0.4	0.7
Mobile	0.009	332,000	535,000	143,000	189,000	392,000	2.3	3.7
Boston	0.020	804,000	1,294,000	143,000	661,000	1,151,000	5.6	9.1
Los Angeles	0.004	126,000	204,000	143,000	(17,000)	61,000	0.9	1.4
Philadelphia	0.012	451,000	725,000	143,000	308,000	582,000	3.2	5.1

TABLE 7-14. Estimated Cost Effectiveness of Facility 8 for US Shipyard Locations

Location	Total Shipyard Productivity Increase (Fraction)	Annual Savings $ Low	Annual Savings $ High	Annual Cost($)	Net Annual Savings (Loss)$ Low	Net Annual Savings (Loss)$ High	Savings To Cost Ratio Low	Savings To Cost Ratio High
Baltimore	0.009	346,000	558,000	578,000	(232,000)	(20,000)	0.6	0.9
New Orleans	0.005	183,000	293,000	578,000	(395,000)	(285,000)	0.3	0.5
Portland, OR	0.006	209,000	335,000	578,000	(369,000)	(243,000)	0.4	0.6
Norfolk, VA	0.008	297,000	478,000	578,000	(281,000)	(100,000)	0.5	0.8
Portland, ME	0.009	369,000	593,000	578,000	(209,000)	15,000	0.6	1.0
New York	0.010	381,000	612,000	578,000	(197,000)	34,000	0.7	1.0
Houston	0.008	311,000	500,000	578,000	(267,000)	(78,000)	0.5	0.9
Galveston	0.008	303,000	488,000	578,000	(275,000)	(90,000)	0.5	0.8
Seattle	0.009	325,000	524,000	578,000	(253,000)	(54,000)	0.6	0.9
San Diego	0.001	31,000	50,000	578,000	(547,000)	(527,000)	0.5	0.8
Mobile	0.007	259,000	417,000	578,000	(319,000)	(161,000)	0.4	0.7
Boston	0.012	487,000	784,000	578,000	(91,000)	106,000	0.8	1.4
Los Angeles	0.003	95,000	153,000	578,000	(483,000)	(425,000)	0.2	0.3
Philadelphia	0.008	302,000	486,000	578,000	(276,000)	(92,000)	0.2	0.8

higher combined wind-cold effect than other shipyard. locations. In addition, potential savings from water and snow removal (Table 7-15) would tend to make this facility more attractive in these marginal locations. Table 7-15 is based on limited data for one year from two locations and may only approximate the costs of those and other locations. Water removal costs are high, however, and a partial or complete covering of the shipways could reduce a substantial part of these costs.

TABLE 7-15. Estimated Annual Costs for Water and Snow Removal

Location	Annual Inches Precipitation	Annual Inches Snow	Annual For Cost Water Removal	Annual Cost For Snow Removal	Total Cost
Houston	45.79	0.4	$68,685	$ 400	$ 69,085
Portland, Maine	42.85	77.0	64,275	48,500	112,775
Portland, Oregon	37.18	8.2	55,770	4,100	59,870
Norfolk	44.94	7.2	67,410	7,200	74,610
Galveston	41.81	0.2	62,715	200	62,915
New York	43.93	26.2	65,895	23,100	88,995
Baltimore	43.05	23.5	64,575	21,750	86,325
Seattle	38.94	16.1	58,410	16,100	74,570
Philadelphia	42.48	21.3	63,720	20,650	84,370
San Diego	10.40	T	15,600	--	15,600
Mobile	68.13	0.4	102,195	400	102,595
Boston	42.77	42.8	64,155	31,400	95,555
Los Angeles	12.63	T	18,945		18,945
New Orleans	53.90	0.2	80,850	200	81,050

SECTION 8. CONCLUSIONS AND RECOMMENDATIONS

The analyses of productivity increases from the use of wether protection facilities at U.S. shipyards showed that substantial savings could be realized by the use of certain facilities. Specifically, the analyses showed that:

- Covering the outdoor work in the platen assembly areas would be cost-effective in all locations except southern California. Cost-effective covering included portable buildings ("Wonder Buildings"), open-sided sheds, or completely enclosed, heated, facilities. The latter two appear to be so cost-effective that we recoammend shipyards outside of southern California analyze the cost-effectiveness of these facilities, independently, for their specific application. Since our analysis was limited to productivity increases directly attributable to weather, greater savings than those indicated would result because covering would also permit the installation of more automated equipment and increase quality.
- Hoarding panels for work on the shipways and outfitting wharf were extremely cost-effective in nearly all locations. The use of hoarding panels should be evaluated in greater depth since these are inexpensive and tend *to* produce a large return on investment. There is little current application of this method of protection in shipbuilding. An easily assembled and disassembled design would be useful for these applications.
- The best combination of weather protection facilities was the use of hording panels on the shipways and heated steel buildings with telescoping or removable roofs on the platen areas. In some locations, unheated steel sheds, open one side, were more cost-effective in the platen areas than the completely enclosed, heated buildings.
- Portable steel or air-inflatable buildings covering assembly areas were also cost-effective, but generally less than the more permanent types of structures.

- Sun nets were beneficial for the platen areas of most southern shipyards and may also be beneficial for the shipways and outfitting wharf.
- Partial or complete coverage of shipways was uneconomic or marginal stall locations.
- A blasting, painting and drying shop was marginal for the standard shipyard at most locations unless painting of panels and sub-assemblies is on the critical path. In this' case, paint shops would be generally economic at most locations.
- Nearly all forms of weather protection devices were found to be uneconomic or marginal for southern California shipyards.

Other conclusions reached in the course of the study were:

- Most shipyard estimates of productivity increases that could be gained from putting outside work undercover were in the range of 20% to 30%.
- There was general agreement among shipyards, the construction industry and the literature that adverse weather conditions significantly reduce productivity in the shipbuilding and heavy construction processes. The weather conditions having the greatest detrimental effect are rain, wind, and cold weather. However all types of adverse weather influence productivity to some extent. These include high temperature, high humidity, fog, snow and sleet.
- Considerable use is presently being made of weather protection facilities in U.S. shipyards in the northern climates. However, much of U.S. shipbuilding is conducted in the open where adverse weather can affect the work.

Recommendations

- Adverse weather has a significant effect on productivity, as indicated by our model. It is recommended that the shipyards conduct specific engineering studies on the effect of weather on the productivity of specific tasks at denigrated locations to verify the magnitude of these effects.

The present study was based on estimates of the productivity of various crafts under different weather conditions and work locations. Actual measurements of productivity of workers performing various tasks under different climatic conditions would provide a more definitive analyses. Sime this is an industry-wide problem which affects our competitive position with foreign shipyards, a cooperative government-industry program like the present one would appear to be mutually beneficial.

- Investigations of alternative weather protective structure designs and limited test applications need to be made to establish which are the most cost-effective facilities. The demonstrations should be undertaken at selected shipyard locations in order to determine productivity gains under actual adverse weather and to assess the potential cost-effectiveness at other shipbuilding regions.